4) Comments

Although SSB interference had little effect on baseline SSB intelligibility, a slightly higher level of background noise was noted by the listeners.

The similar resistance of SSB to FM interference in all but weak signal strength areas was also noted in the comments in which the results from high signal strength areas were described as "good" and "excellent", while the weak signal strength tape was described in one case as "difficult".

5) Summary

SSB is highly resistant to SSB adjacent channel interference and also resistant to FM interference except in low signal strength areas, where it causes a 2% drop in intelligibility. SSB is much less resistant to AM interference under all conditions.

SSB adjacent interference has only a mild effect on AM, and this effect is particularly small in low signal strength areas. Its effect on FM is larger, but not very serious.

Table 4.7: Adjacent Channel Voice Results

SSB	Baseline	SSB Int	FM Int	AM Int
A217	6	6.1	6.4	7.4
A2022	6.9	7.7	3.7	10.1
A3	8.6	8	10.8	10.1

FM	Baseline	SSB Int
A217	6.5	4.2
A2022	7.3	10.9
A3	24.8	19.5

AM	Baseline	SSB Int
A217	11.8	15.6
A2022	14.8	14.9
A3	23.4	26.4

Fig 4.20: Voice on SSB with adjacent channel interference

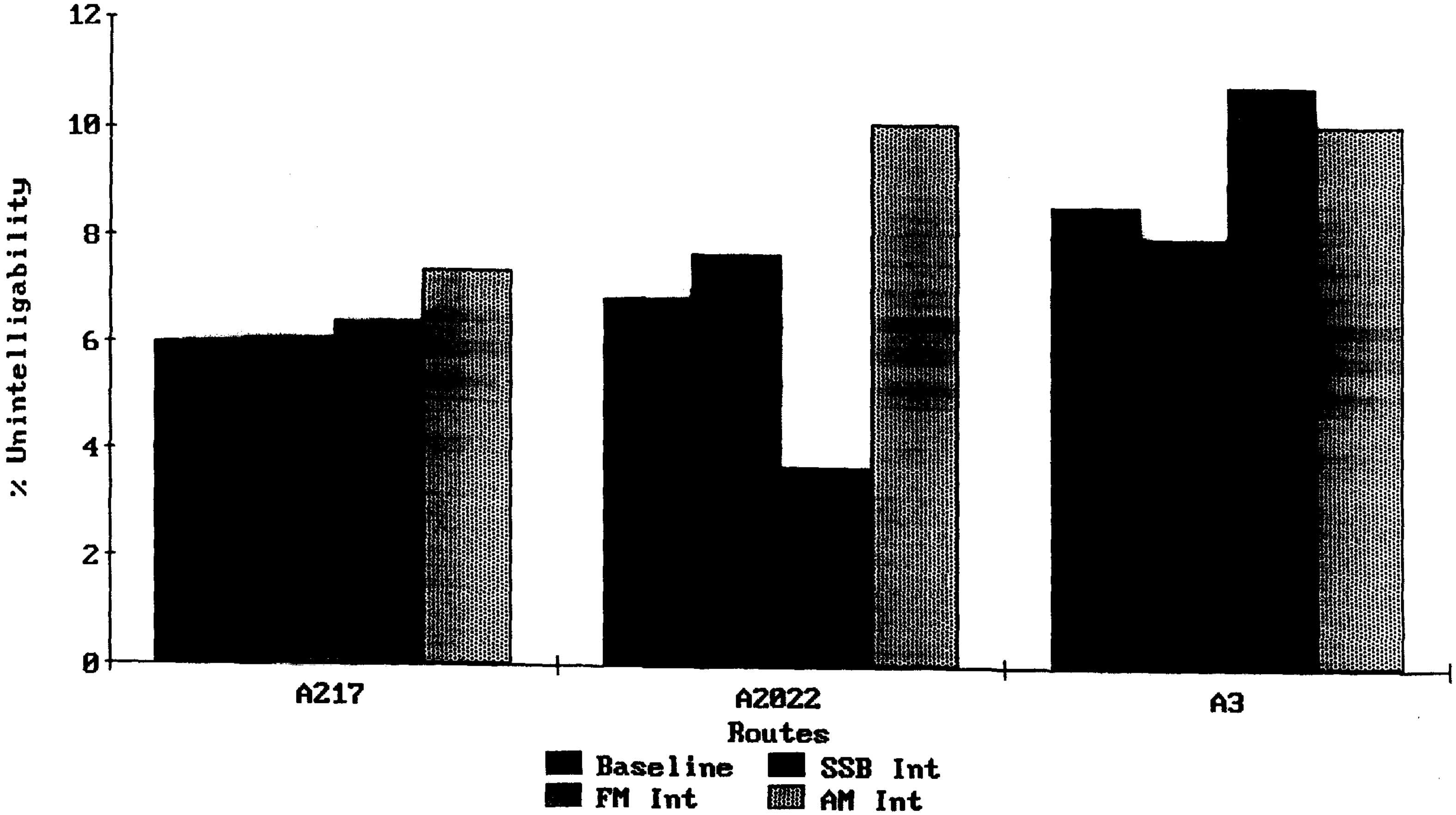


Fig 4.21: Voice on FM with SSB adjacent channel interference

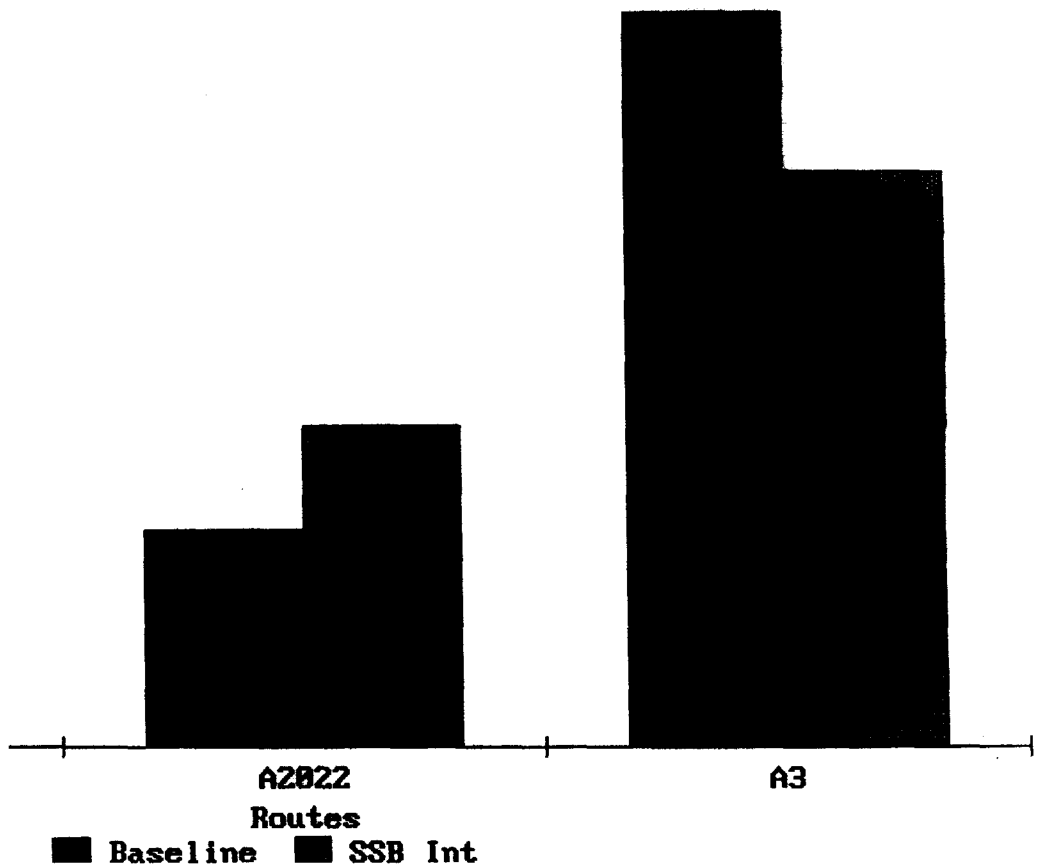
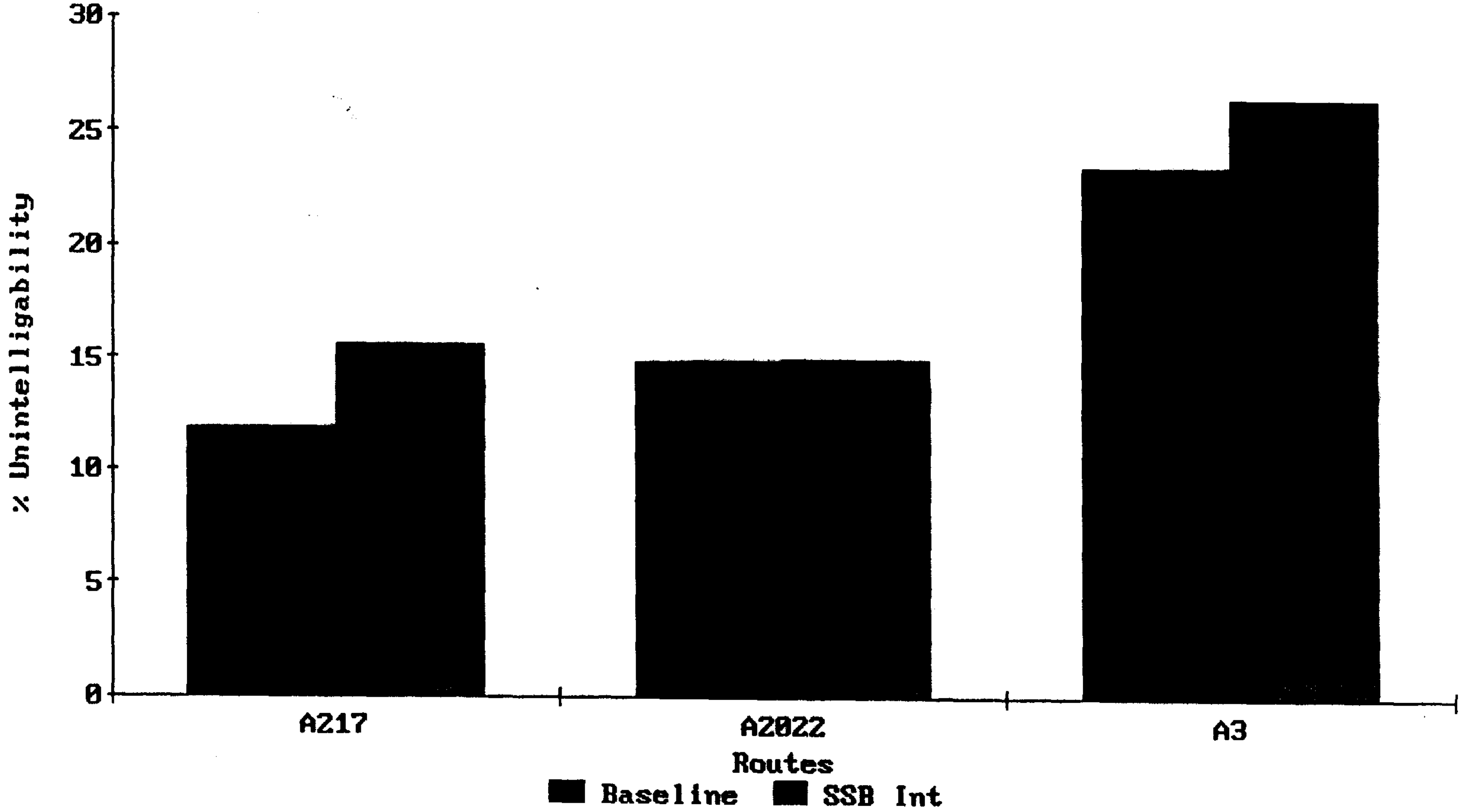


Fig 4.22: Voice on AM with SSB adjacent channel interference



4.2.4 Co-Channel Voice Results

Table 4.8 gives the results for co-channel interference tests, and Figs 4.23, 4.24, and 4.25 show these results in graphical form. As for the data runs, co-channel measurements were restricted to route (3) - A2022. The following sections describe the results, and estimates are made for the protection ratios required to obtain unchanged intelligibility scores, based on the results obtained.

1) SSB with Co-channel Interference

As described in Section 4.1.3, a different SSB transmitter was used for the wanted channel in the co-channel tests to that used in the other measurements. The results obtained are therefore only comparable in terms of relative levels with earlier and later results.

Referring to Fig 4.23, it can be seen that SSB interference has the least effect on an SSB wanted channel. This is a rather surprising result because the SSB receiver actually demodulates the continuous speech of the interfering channel so that this can be clearly heard. This is obviously extremely distracting and confusing for a listener, both in a real situation and in the situation of the DRT test. Thus, the fact that the intelligibility performance of SSB is degraded by less than 8% by an interference with 8dB average wanted-to-interference ratio is encouraging. A higher level interference has a more serious effect, but dropping the interference level improves the performance radically so that the estimated protection ratio required in an SSB system is 20dB.

It should be noted that with a data interferer, the intelligibility score would probably rise, since this interference would only be perceived as increased background noise, rather than as a superimposed conversation.

An FM interferer subjects the received SSB wanted channel to frequency jitter when the FM carrier is within the SSB notch and this has a very serious effect on intelligibility. At other times, the background noise level is considerably increased, so that in total an FM interferer has the most serious effect on SSB with the highest level giving a near unintelligible result. However, increasing the wanted-to-interference ratio gives a major improvement of over 10% on the intelligibility score. This indicates a required protection ratio of around 25dB.

An AM interferer has a less serious effect than FM and produces a less pronounced increase in the level of noise. However, since this noise is in the form of an extremely irritating and intrusive whine (as the AM carrier is demodulated), AM is subjectively perceived by the listeners as the most serious source of interference. In addition, the performance of SSB does not improve greatly when the level of AM interference is dropped and so it is estimated that with AM interference, SSB will require the highest protection ratio so far, at a level of at least 30dB.

Although the two transmitters were set up to superimpose the AM carrier with the TTIB pilot tone, the carrier could be heard (and therefore must be outside the SSB pilot notch) because of frequency drift by the AM transmitter.

2) FM with SSB Co-channel Interference

FM baseline results were again taken for the co-channel tests to check the reliability of these results, but these agreed well with the previous results, and the problem encountered with SSB was not repeated.

As can be seen in Fig 4.24, FM was found not to be very resistant to SSB interference, which increased the background noise by a considerable margin. In addition, there is a partial demodulation of the SSB interferer, so that the interfering voice can be heard, though not interpreted. Only a small improvement was encountered with the decrease in interference level, so that a higher protection ratio is required for SSB interfering with FM than was required in the reverse situation. The estimated value is around 30dB.

3) AM with SSB Co-channel Interference

As can be seen in Fig 4.25, SSB has a completely destructive effect on AM intelligibility at the highest interference level, with the increased background noise and partially demodulated voice causing near complete loss of the AM voice. However, lowering this level improved the situation radically, so that the required protection ratio is likely to be only around 20dB.

4) Comments

The difficulty of interpreting the DRT tape for an SSB wanted channel with an SSB co-channel interferer providing intelligible interference was much commented on, but in comparison with the two other interference types, the remarks were mild. FM interference was described as "terrible" and "horrendous", while AM was considered "unpleasant", "unnatural" and one listener claimed to be reminded of the dentist - a reference to the infuriating whine.

The comments for AM and FM with SSB interference merely commented unfavourably on the level of background noise.

5) Summary

In general, therefore, SSB is fairly resistant to SSB co-channel interference and fairly resistant to FM interference except at very high levels. However, the limiting factor is likely to be AM interference which causes an extremely irritating whine under worst case conditions which is not particularly sensitive to interference level changes.

On the other hand, AM is in fact quite resistant to SSB interference except at very high levels of interference, while FM is seriously affected under all conditions investigated.

The highest required protection ratio is estimated to be around 30dB.

Table 4.8: Co-channel Voice Results

SSB

Baseline	23.1
Co SSB	41.4
Co SSB/att	30.6
Co FM	49.9
Co FM/att	39.4
Co AM	40.6
Co AM/att	35.2

FM

Baseline	7.3
Co SSB	21.3
Co SSB/att	17.6

AM

Baseline	14.8
Co SSB	52.5
Co SSB/A	24.7

Fig 4.23: Voice on SSB with co-channel interference

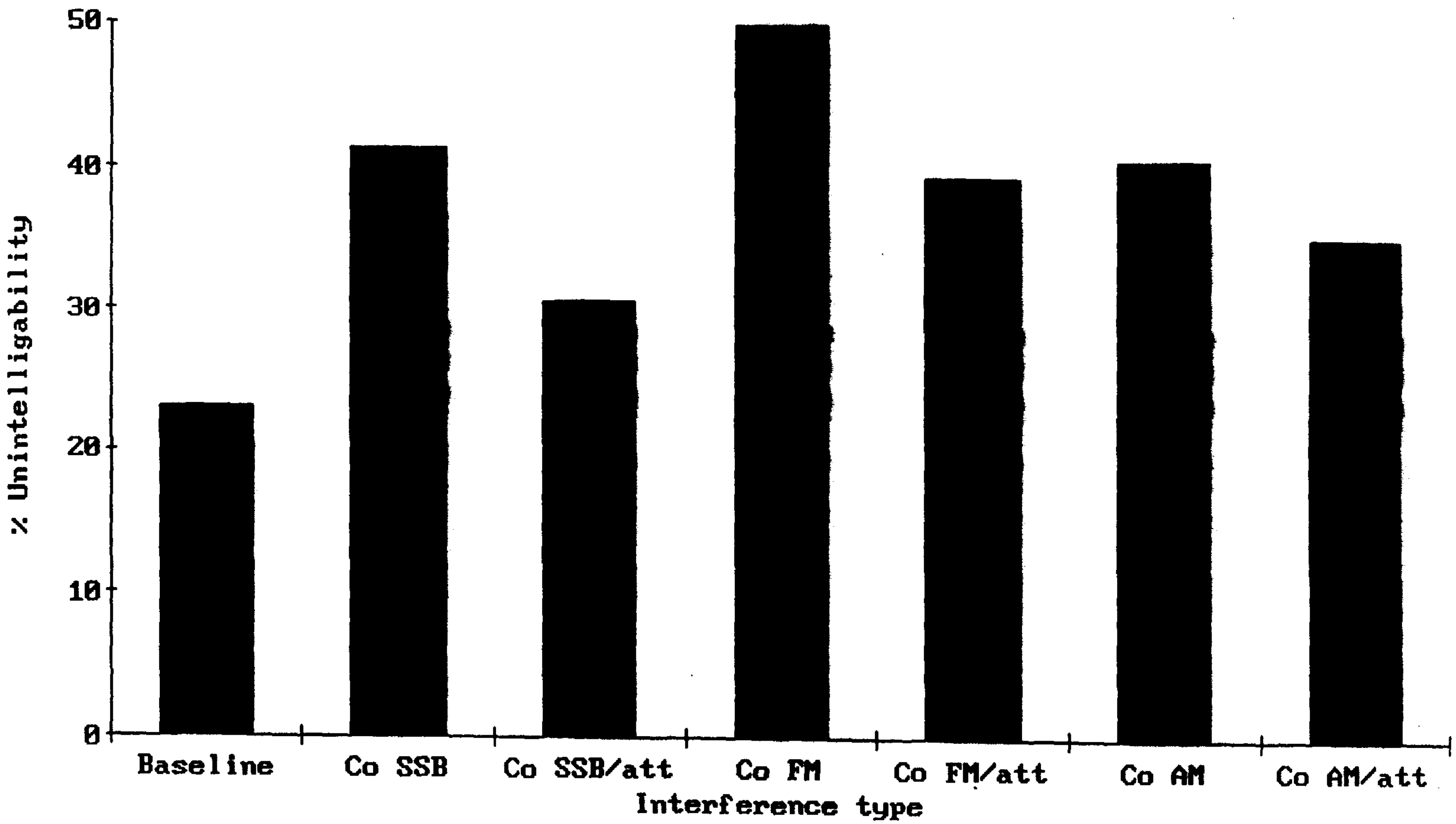
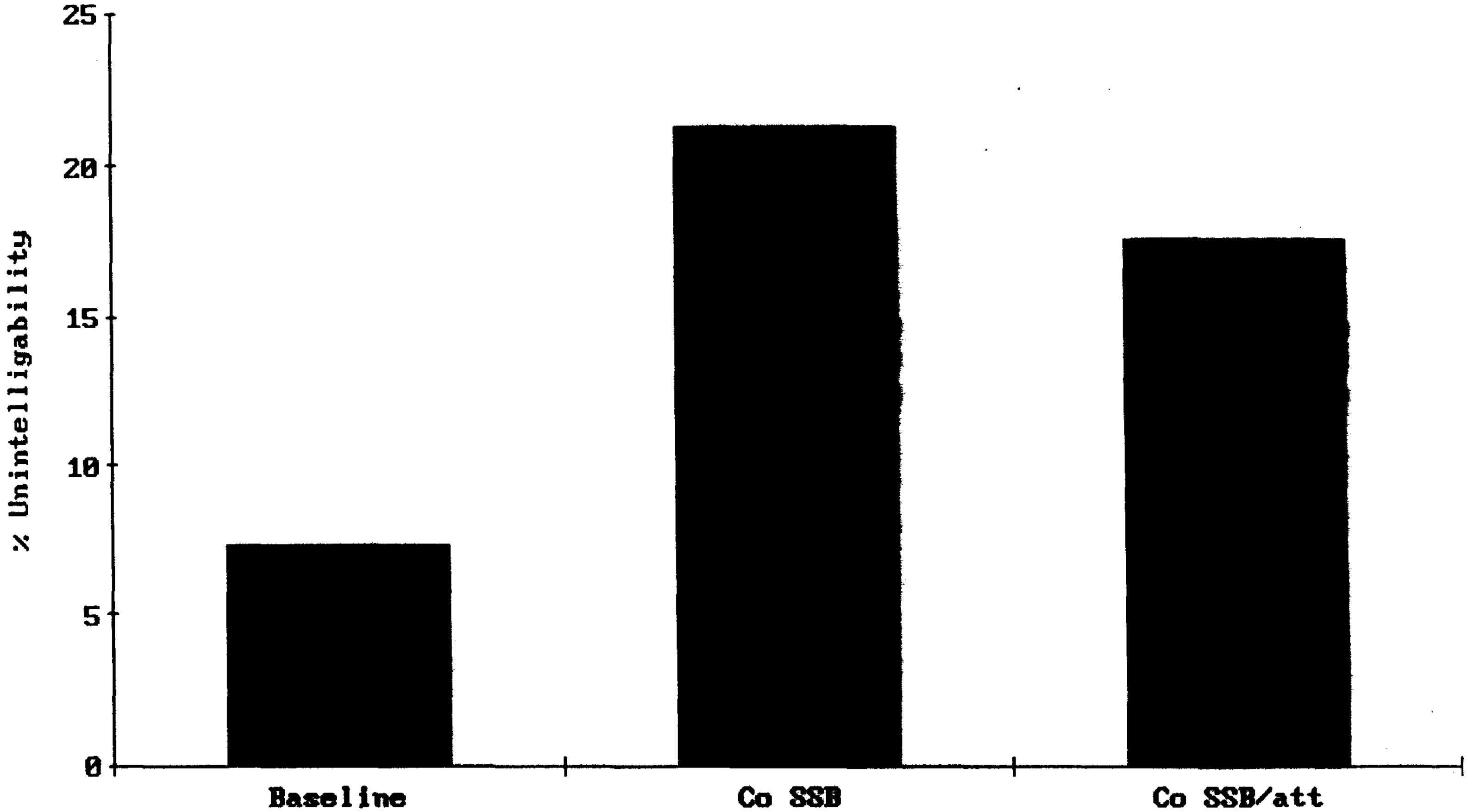


Fig 4.24: Voice on FM with SSB co-channel interference



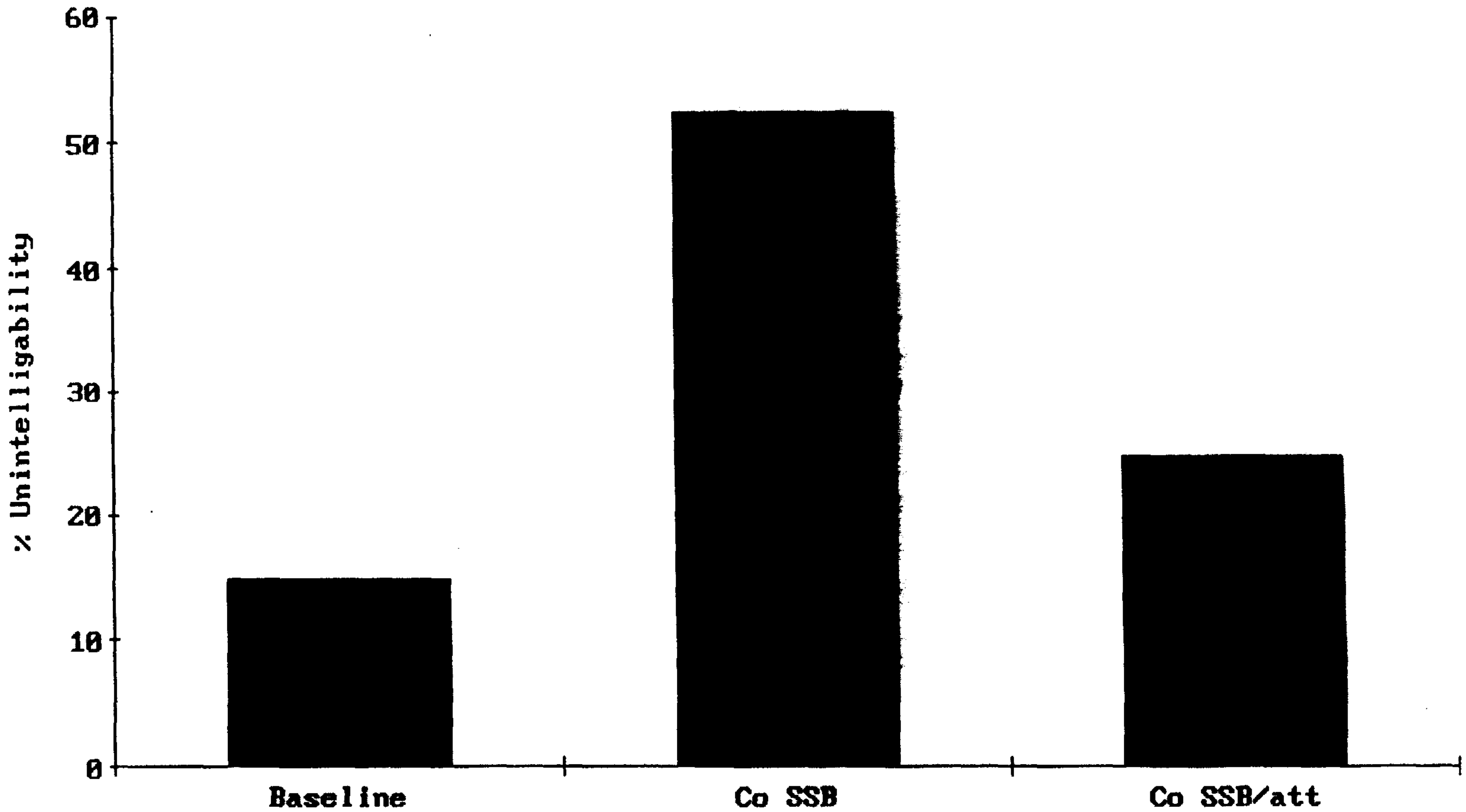


Fig 4.25: Voice on AM with SSB
co-channel interference

4.2.5 Voice Results Summary

In considering the voice results, the difficulties encountered with the SSB equipment reliability and with a few particular aspects such as the VOGAD circuit, should be noted. It is thought that the SSB results represent a threshold of performance which could probably be raised with only a few minor modifications. The overall system reliability caused problems during the trial, but this was to be expected with a development system and should not be a feature of any future fully developed system.

In essence, SSB demonstrates better intelligibility on average than either AM or FM. AM only performs better under very high signal strength conditions and FM never significantly surpasses SSB and deteriorates more rapidly in very low signal strength areas. In contrast, SSB demonstrates very little dependance on signal strength levels under any measured conditions.

However, despite its high objective intelligibility, SSB is unpopular with listeners, who find its tone unpleasant. The degree to which this is a disadvantage depends on the application, and of course it is possible that the subjective quality of the voice might be improved by adjusting the receiver audio processing.

In terms of interference, SSB is resistant to both SSB and FM adjacent channel interference and the limiting factor is likely to be AM interference. SSB voice has no major effect on existing AM and FM systems.

For co-channel interference, SSB has an appreciable effect on FM. SSB also suffers itself from AM interference, both in terms of objective intelligibility and subjective listener comfort. The projected protection ratio for retaining the same level of intelligibility under interfering conditions is about 30dB minimum wanted-to-interference ratio.

4.3 Trunking Performance

Both FM and SSB systems operated using MPT1327 standard trunking which uses a control channel with FFSK 1.2kb/s data to set up traffic channels. In general, both systems operated equally well, but FM entered the scanning mode, where it is unable to lock onto the control channel, at a slightly higher signal strength threshold level than SSB. (This level was still less than 0dBμV). This was in accordance with the results obtained for FSK 1.2kb/s data, where SSB performed markedly better in low signal strength areas.

5 Conclusion

The general opinion of the trials team on the performance of the LM-SSB equipment under test was overall very favourable.

a) Data

Data performance (at 1.2kb/s and 2.4kb/s) for SSB was found to be at least comparable to and in most cases better than either of the two 12.5kHz bandwidth AM or FM systems (AM being markedly worse than SSB).

Although not immediately relevant to the introduction of LM-SSB alongside existing modulation schemes, faster data rate experiments were performed. It was found that FM performed significantly better than LM-SSB at data rates of 4.8kb/s and above. However, it has been shown[26] that efficient data transmission at 9.6kb/s is possible using an adapted LM-SSB system (and even with the standard system, with higher error rates). The evidence therefore suggests that it is not the TTIB/FFSR processing that is the cause of the poor 4.8kb/s and 9.6kb/s data performance. Rather, it is a combination of the RF sections of the system, particularly the crystal filter which was originally designed for voice and 1.2kb/s data, and the use of general purpose line MODEMs with an unadapted LM-SSB system, that impedes the fast data transmissions.

The SSB system was found to be resilient to adjacent channel interference, only being noticeably susceptable in very bad receiver conditions of weak signal strength and deep fading. This was also true for the FM and AM systems under SSB interfering conditions. It is interesting to note that in all cases, SSB performed better with any form of adjacent channel interference than did either FM or AM without interference.

As a result of the co-channel tests that were performed, a potential problem area was identified. Although FM and SSB wanted channels were only mildly affected by an SSB interferer, an interfering co-channel SSB signal had seriously deleterious effect on an AM channel. Consideration must be given to the facts that the measurements were taken under extreme interfering conditions (the average co-channel protection ratios of 2dB and 8dB were chosen specifically to provide a severe test), and that a very few AM data transmissions exist in the PMR frequency bands. Hence it was concluded that this particular interference scenario is unlikely to occur and is therefore not regarded as a serious problem in the spectral integration of LM-SSB.

SSB was found to be susceptable to both FM and AM co-channel interference with low protection ratios, but its performance improved greatly when the protection ratio was improved. These results suggested that the adoption of a protection ratio of 30dB would result in a minimal degredation of channel quality.

b) Voice

The voice intelligibility of the LM-SSB system was, in general, found to be comparable to that of FM and more consistant than that of AM. SSB performed at a consistant level of 92% intelligibility and was mostly unaffected by fading or signal strength. However, the general opinion of listeners was that SSB voice was highly intelligible, but at the same time unpleasant to listen to. Referring to the former, it is suggested that the intelligibility can be further improved by optimisation of the VOGAD circuitry to prevent the corruption of the first syllable of each word. Similarly, the tonal quality could also be altered to improve the bass response which would, to a certain extent, remove the "tinny" quality associated with the SSB system. Neither of these problems are inherent in LM-SSB, but are a function of the particular implementation used.

Of the three modulation schemes, AM was found to be the most natural and easy to listen to, although this performance degraded rapidly with decreasing signal strength.

From the adjacent channel results, SSB was found to be very resilient to all three types a co-channel AM interferer. Although the objective intelligibility level was comparable with that obtained with FM interference, co-channel AM interference caused what was described as an extremely irritating whine, which was found to be particularly insensitive to interference level changes. This was, in fact, the AM carrier being demodulated by the SSB system as a tone (which explains its very high level). A wanted-to-interference ratio of 30dB was projected as providing a suitable level of protection.

c) General

In general, it must be stressed that the LM-SSB equipment tested was still very much a prototype system and was compared to conventional modulation schemes, most notably FM, that have undergone years of development. This was particularly obvious at the start of the trials when very specific hardware and software faults were identified and which had to be corrected before the trials were allowed to continue.

Although anomalies do exist in the results (see section 4) satisfactory explanations have been put forward for most of these and the results show a generally consistant behavour. The combination of TTIB and FFSR processing give excellent data performance and a generally acceptable voice quality, although the possibility does exist for improvement in the voice acceptability for a modest engineering overhead. SSB was found to be generally very resistant to adjacent channel interference, although co-channel experiments suggest that care must be taken when allowing AM and SSB systems to exist in a co-channel environment. A co-channel protection ratio of 30dB is suggested as providing complete protection for the co-existence of systems utilising different modulation schemes. A similar, or slightly lower, level of protection ratio would be required to provide the same degree of protection in an environment utilising only SSB.

Finally, the overall conclusion is that, provided care is taken, LM-SSB is integrable into the existing PMR environment. It is felt that LM-SSB will provide an effective mechanism for relieving the spectral congestion currently experienced in the PMR system, while causing little disruption to the existing PMR infrastructure.

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Appendices

(i) Lab Test Schedule.

(ii) Draft DTI Specification

(iii) Test Equipment

(iv) Raw Data Results

(v) High Speed Data Modem Configurations

(vi) Voice Results

Appendix (i) : Lab Test Schedule

1. Equipment Laboratory Tests.

The following is a series of lab tests that will be required to be performed on the SSB equipment that will be used in the trials. They are based extensively on the new draft DTI specification relating to SSB equipment (as discussed at the last meeting). It is referred to as the revised DTI spec.

The test list was based on the DTI specification inorder to be able to relate the field trial results to the limits applied in the lab through the DTI specification. Unless stated otherwise, tests should be carried out on both the mobile and base stations.

2. Transmitter Measurements.

Only measurements under normal test conditions are required.

2.1 Frequency Error.

To be carried out as per BS6160:Part 4: Section 7. In addition, the frequency error for the mobile in both a locked and unlocked state is required (as per section 4.1.3 revised DTI spec.).

2.2 Peak Envelope Power (PEP).

Method of measurement as section 4.2.2 revised DTI spec, with the exception that the level of the applied modulation shall be 10dB above that required to give half the rated PEP (rather than 20dB).

2.3 Audio Frequency Response.

Method of measurement as section 4.3.2 revised DTI spec. Any audio processing or pre-emphasis will be active during the test.

2.4 Adjacent Channel Power.

Method of measurement as section 4.4.2 revised DTI spec. Also required are measurements of channel power two channel spacings above and two channel spacings below the channel under test.

2.5 Spurious Emissions.

The measurements for spurious emission power level are to be carried out as section 4.5.2, revised DTI spec. Measurements for the effective radiated power (section 4.5.3, revised DTI spec) are not required for the mobile equipment. However, if a suitable test area can be found, measurements for the base station effective radiated power (cabinet radiation) should be carried out.

2.6 Intermodulation Attenuation.

Measurements to be carried out as section 4.6.2 revised DTI spec. Which test configuration used (circulator or resistive attenuator) should be stated along with the test results.

2.7 In-Band Intermodulation Response.

The purpose of this test is to measure transmitter power amplifier non-linearity on adjacent channels. Standard test modulation B shall be applied and the intermodulation product levels on both the upper and lower adjacent channels measured.

2.8 Transmitter Attack Time.

Measurements to be carried out in accordance with BS6160:Part 4: Section 16.

2.9 Audio Frequency Harmonic Distortion Factor.

Measurements to be carried out in accordance with BS6160:Part 4: Section 13.

3. Receiver Measurements.

Sensitivity, adjacent channel selectivity and spurious response all require the use of applied RF signals and SINAD measurements. This will be a problem when testing the mobiles, as discussed at the last meeting. Hence the method of producing the test signal will, for the present, be left unspecified.

3.1 Maximum Usable Sensitivity.

Measurements to be carried out as section 5.1.2 revised DTI spec.

3.2 Adjacent Channel Selectivity.

Measurements to be carried out as section 5.2.2 revised DTI spec.

3.3 Spurious Response Rejection.

Measurements to be carried out as section 5.3.2 revised DTI spec.

3.4 Intermodulation Response Rejection.

Measurements to be carried out in accordance with BS6160:Part 5: Section 14.5.2. Note that the "standard signal to noise ratio" is the 12dB SINAD level (see BS6160:Part 5: Section 3.3). Frequencies f_n and f_r are to be one channel spacing plus 1kHz and two channel spacings plus 1kHz above the test channel.

3.5 Blocking.

Measurements to be carried out as section 5.5.2 revised DTI spec.

3.6 Spurious Emissions.

Measurements for spurious emission power level to be carried out as section 5.6.2 revised DTI spec.

Measurements for the effective radiated power (cabinet radiation) should be carried out as section 5.6.3 for the base station equipment if a suitable test area is available. Measurements of cabinet radiation are not required for the mobile.

3.7 Harmonic Distortion Factor.

Measurements to be carried out in accordance with BS6160:Part 5: Section 9.

3.8 Co-Channel TTIB-Tone Test.

A measurement showing the effects of a co-channel TTIB tone is required. The exact nature of the test is to be determined at a later date.